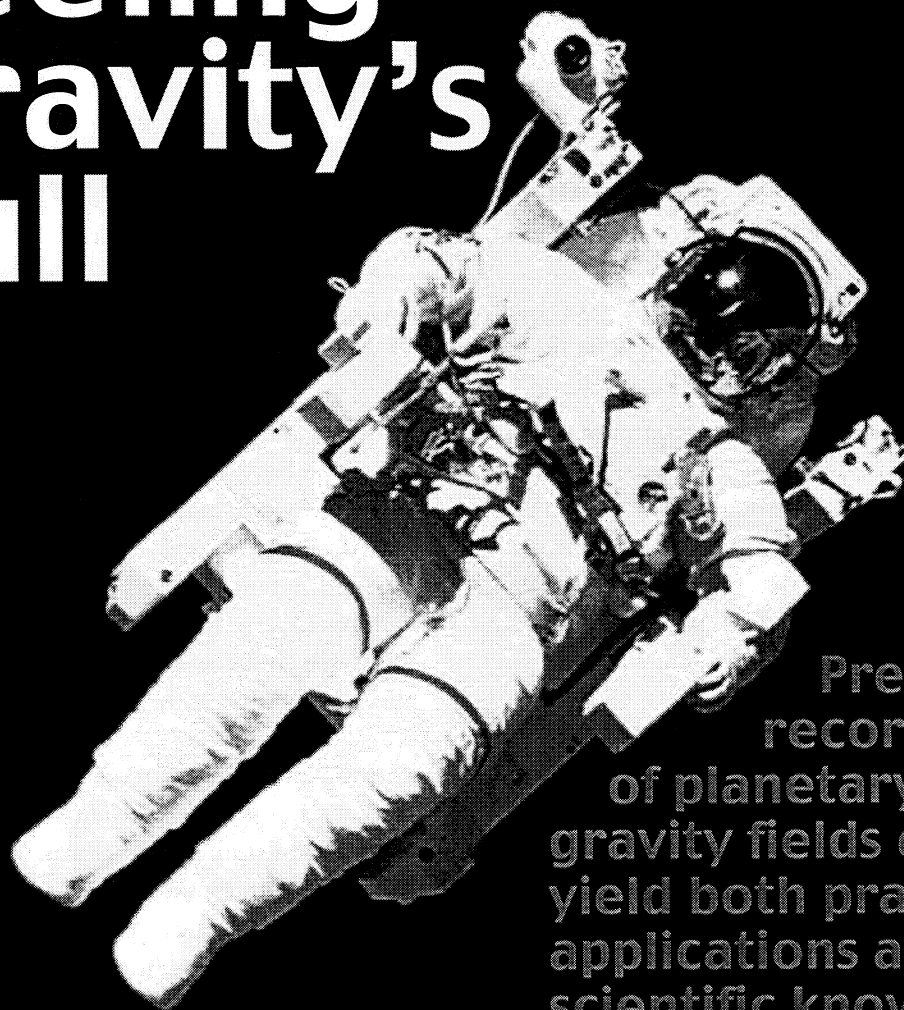


Feeling Gravity's Pull



Precise recordings of planetary gravity fields can yield both practical applications and scientific knowledge



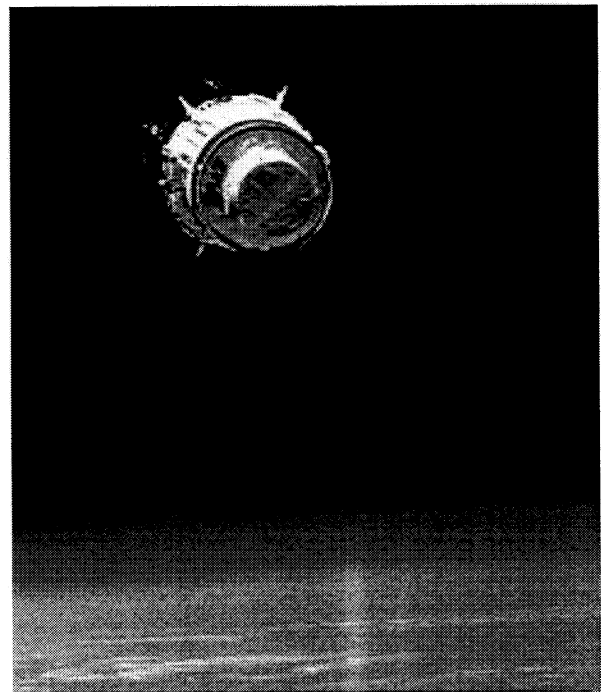
Most people take the constant presence of gravity's pull for granted. However, the Earth's gravitational strength actually varies from location to location. This variation occurs because mass, which influences an object's gravitational pull, is not evenly distributed within the planet. Changes in topography, such as glacial movement, an earthquake, or a rise in the ocean level, can subtly affect the gravity field.

An accurate measurement of the Earth's gravity field helps us understand the distribution of mass beneath the surface. This insight can assist us in locating petroleum, mineral deposits, ground water, and other valuable substances. Gravity mapping can also help notice or verify changes in sea surface height and other ocean characteristics. Such changes may indicate climate change from polar ice melting and other phenomena. In addition, gravity mapping can indicate how land moves under the surface after earthquakes and other plate tectonic processes. Finally, changes in the Earth's gravity field might indicate a shift in water distribution that could affect agriculture, water supplies for population centers, and long-term weather prediction.

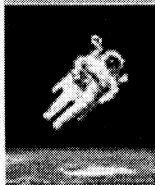
Scientists can map out the Earth's gravity field by watching satellite orbits. When a satellite shifts in vertical position, it might be passing over an area where gravity changes in strength. Gravity is only one factor that may shape a satellite's orbital path. To derive a gravity measurement from satellite movement, scientists must

remove other factors that might affect a satellite's position:

- Drag from atmospheric friction
- Pressure from solar radiation as it heads toward Earth and as it is reflected off the surface of the Earth
- Gravitational pull from the Sun, the Moon, and other planets in the Solar System
- The effect of tides
- Relativistic effects



Perturbations in the flight path of a satellite may indicate a change in the strength of the Earth's gravity field.



Scientists must also correct for the satellite tracking process. For example, the tracking signal must be corrected for refraction through the atmosphere of the Earth.

Supercomputers can calculate the effect of gravity for specific locations in space following a mathematical process known as *spherical harmonics*, which quantifies the gravity field of a planetary body. The process is based on Laplace's fundamental differential equation of gravity. The accuracy of a spherical harmonic solution is rated by its degree and order.

Minute variations in gravity are measured against the *geoid*, a surface of constant gravity acceleration at mean sea level. The geoid reference gravity model strength includes the central body gravitational attraction (9.8 m/s^2) and a geopotential variation in latitude partially caused by the rotation of the Earth. The rota-

tional effect modifies the shape of the geoid to be more like an ellipsoid, rather than a perfect circle. Variations of gravity strength from the ellipsoidal reference model are measured in units called *milli-Galileos* (mGals). One mGal equals 10^{-5} m/s^2 .

Research projects have also measured the gravity fields of other planetary bodies, as noted in the user profile that follows. From this information, we may make inferences about our own planet's internal structure and evolution. Moreover, mapping the gravity fields of other planets can help scientists plot the most fuel-efficient course for spacecraft expeditions to those planets.

Reference

National Research Council, *Satellite Gravity and the Geosphere*, National Academy Press, 1997



Research Profile: The Gravity Field of Mars

Investigators:

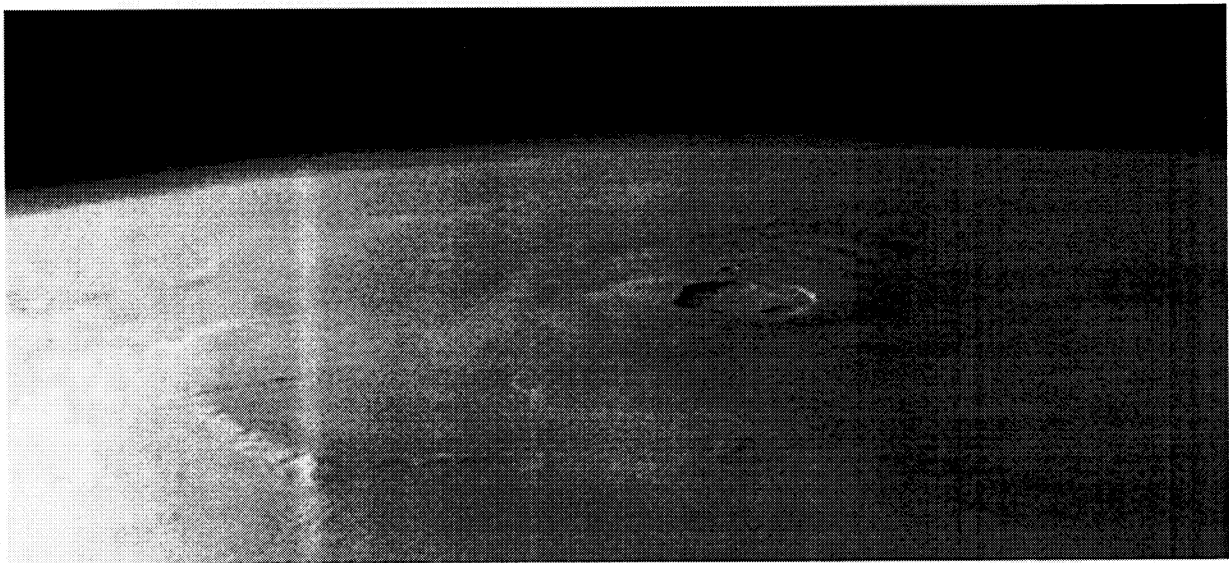
Frank Lemoine, David Smith, and David Rowlands, NASA Goddard Space Flight Center, Laboratory for Terrestrial Physics; Maria Zuber and G. Neumann, Massachusetts Institute of Technology, Department of Earth, Atmospheric, and Planetary Sciences; Douglas Chinn and D. Pavlis, Raytheon ITSS Corp.

This research project developed the Goddard Mars Model 2B (GMM-2B), the first global spherical harmonic solution for the Mars gravity field. Scientists derived the GMM-2B by tracking the orbit of the Mars Global Surveyor (MGS) between October 1997 and February 2000.

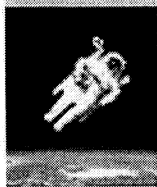
The solution has a degree and order of 80. In comparison, the first Mars gravity solution, which was based only on Mariner 9 data, had a degree and order of 6. According to

Frank Lemoine, the equations of the GMM-2B included roughly 6,600 parameters for modeling the gravity field and another 5,000 for modeling the individual orbits of the MGS.

The orbital path of the MGS was lower, more complete, and more stable than the previous Mariner and Viking crafts, enabling improvements in the geopotential calculation. In addition, the MGS had radio equipment that was less sensitive to disturbances caused by solar plasma.



Topographical features such as the Olympus Mons crater may vary the distributions of land mass and create variations in the gravity field of Mars. *Image credit: NASA*



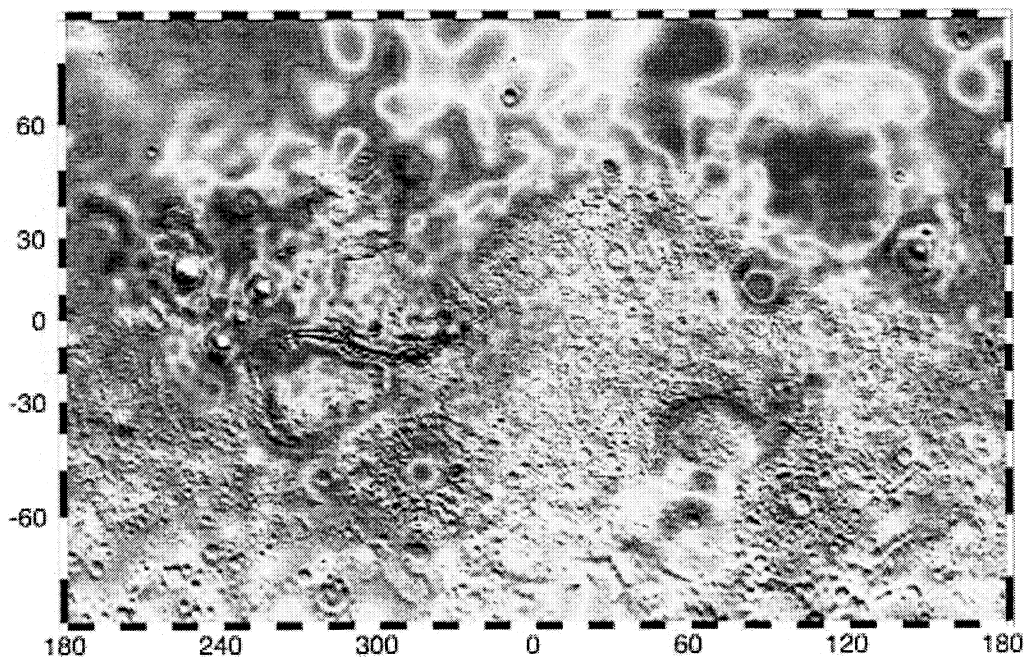
Gravity Modeling

This equipment improved data quality by a factor of 10 over previous Mars mission data.

The researchers processed the spacecraft's orbital path data in individual arcs, each covering 5 days of movement. In each arc, factors such as atmospheric drag, solar radiation pressure, and the thrust maneuvers of the MGS were modeled. To process all this data, the researchers developed 150 equations, each of which consumed 298 megabytes of storage space on the NCCS's UniTree storage system.

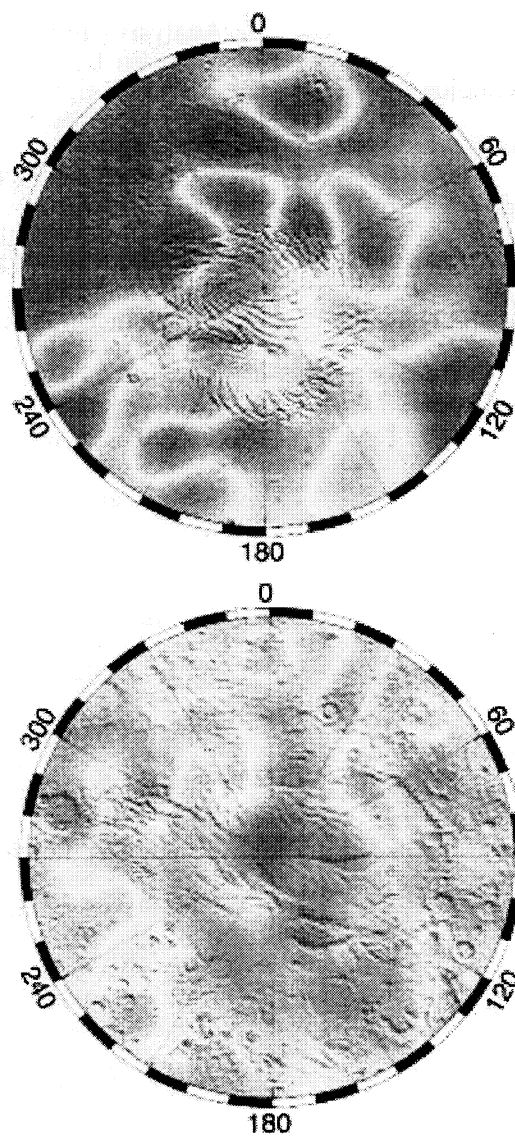
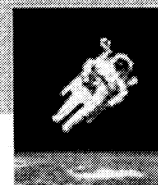
Researchers compared the degree variances for the GMM-2B solutions to the GMM-1 model developed in 1993. Below degree 20, the field accuracy of GMM-2B showed an improvement of two to three orders of magnitude. Beyond degree 20, GMM-1 lacked the global coverage to provide a meaningful comparison.

The research project also mapped out gravity anomalies that GMM-2B had located. The gravity model displayed an improved resolution of the anomalies related to classic geographical features such as the Olympus Mons crater, Tharsis Montes, Elysium, and Isidis.



This map shows gravity anomalies of the planet Mars, as calculated by the GMM-2B. The features now appear with greater power than in the previous Global Mars Model. The anomalies are overlaid on a shaded relief map from the readings of the Mars Orbital Laser Altimeter. *Image credit: NASA*

Gravity Modeling



These circular maps portray gravity anomalies for the northern (top) and southern (bottom) polar regions of Mars. *Image credit: NASA*